CHAPTER 7

ENGINE INTAKE AND EXHAUST SYSTEMS

7-1. Engine intake and exhaust system design features

The function of an engine intake and exhaust system is to deliver combustion air to the engine and dispose of the engine exhaust with as little impact as possible on engine performance. The air intake system may consist of ducts, air filter elements, silencers, etc., as required to lead the combustion air to the engine manifold or blower (turbocharger) air inlet connection. In addition to supplying combustion air to the engine, another important function of the air intake system is to condition the air (usually just particulate removal) to protect engine parts from airborne impurities (dirt and other particulate matter). Air intake systems may also have devices to reduce noise transmitted from the engines. Ducted air intake systems permit the engine to be installed at a location remote from the supply of combustion air. A basic exhaust system consists of an exhaust gas discharge duct, with components to accommodate expansion of the duct, and an exhaust gas silencer (muffler). Some exhaust systems may include components to use the hot exhaust gas to provide the heat for some other process or operation (waste heat recovery), such as fuel oil heating, hot water production, steam generation, etc. When an engine operates within a facility that is protected against attack (blast-protected), the intake and exhaust system must include blast protection features. Maintaining the filter elements, keeping the air intake and exhaust gas discharge points free from obstructions, (such as severely dented or crushed duct sections) that restrict the free flow of combustion air to the engine and exhaust gas from the engine is very important.

a. Basic air intake and exhaust gas systems. A typical basic air intake and exhaust system has air entering the system through an intake air filter. Depending on the size of the engine, the design use of the engine, and the location where the engine is to be used, the air intake filter may range in size from a small replaceable paper filter element to a large filter bank with numerous filter elements. From the intake filter, the air may pass through a separate air intake silencer before reaching the engine combustion air inlet connection. On many engines, the air intake filter may also provide the necessary air intake silencing eliminating the need for a separate air intake silencer. The basic air intake system described might be used on many different kinds of engines (diesel, gaseous fuel, and gasoline) and compressors.

(1) On the normally aspirated diesel engine, the combustion air passes through an air shutoff valve to the engine combustion air distribution manifold and then to individual engine cylinders. On the turbocharged (or air-scavenged) engine, a fan, blower, or compressor device provides compressed air (more pounds of air in the same space) through an air shutoff valve and aftercooler to the engine combustion air distribution manifold. Depending on the engine size and design, the turbocharger device may be standalone (not driven by the engine) or driven by the engine (engine-driven). An engine-driven turbocharger may be directly driven by the engine through a gear or belt drive by the flow of exhaust gases through a turbine section. At the same time the turbocharger (or air scavenger) increases the pressure of the combustion air supplied to the engine, the temperature of the air is also increased. Since the diesel engine is a compression-ignition cycle, an aftercooler may be used on diesel engines to reduce the air temperature low enough to prevent early ignition of the air-fuel mixture.

(2) The operation of a basic air intake system is usually monitored by pressure gauges at the inlet of the engine air intake manifold (on the inlet side of any turbocharger or air scavenger device). As the air intake filter elements become dirty, the vacuum slowly increases. When the vacuum increases beyond an engine manufacturer-specified value, the intake air filter elements may need to be cleaned or replaced. Most systems will have temperature gauges to monitor the exhaust gas temperatures. Systems with

turbocharger or air scavenger devices may also have pressure gauges to monitor the combustion air pressure at the discharge of the device. Systems with aftercoolers may also have pressure gauges to monitor the combustion air pressure at the discharge of the aftercooler and temperature indicators to monitor the combustion air temperature at the inlet and outlet of the aftercooler.

b. Dusty environment air intake system. Engines used in dusty environments may need air intake filters with more face area or, depending on the dust size and frequency of dusty conditions, a series of filters may be required to protect the engine. In areas where the amount of dust in the air varies with weather, the filter system may need to be capable of responding to varying dust concentrations. A common dusty environment air intake and exhaust system is where the engine is installed in a building. Combustion air for the engine is pulled from inside the building through an intake air filter assembly, and the exhaust gas is ducted to outside the building and discharged through an engine exhaust silencer installed outside. The roll filter bank, by advancing either on a timed cycle or when the pressure drop across the filter reaches a preset value, responds to variable dust conditions. The extended filter surface bank (deep cell filter) provides a lot of total filter area compared to the face area of the filter frame to minimize how often filters have to be changed.

c. Blast-protected air intake and exhaust systems. Blast protection can mean different things depending on the type of facility. For this discussion, a blast-protected facility refers to a facility that is designed to withstand a specific blast effect and continue in operation throughout the design level attack.

(1) Figure 7-1 shows a blast-protected air intake system. The engine (not shown on the figure) is located deep within the facility and pulls combustion air from inside the facility through an engine intake air filter. In this example, the air intake is not only providing combustion air to the engines, but is also providing air to occupied spaces within the facility. The example blast-protected intake system utilizes an intake air fan to draw air into the facility. In facilities using intake air fans, there is usually a standby fan installed so that fans can be removed from service for maintenance and so a spare fan is available in the event an in-use fan fails. The example blast-protected air intake system is installed inside a blast-resistant structure. Air enters the structure through an array of blast valve assemblies that are built into the blast-resistant structure. See chapter 32 for a detailed description of blast valves and blast valve operation and maintenance.

(a) In addition to the roll filter assembly and the deep cell filter bank, the example blast-protected air intake system includes a prefilter element and a CBR (chemical-biological-radiological) filter bank. The prefilter is provided to handle short-term, very high dust and debris concentrations that may occur during an attack. Many systems allow intake air to bypass the prefilter during periods when the blast protection system is not in the blast mode of operation. If the blast protection system is in operation, the prefilter may also be bypassed when the filter elements become plugged.

(b) The CBR filter bank removes chemical and biological agents and radioactive particles from the intake air. As with the prefilter, many blast-protected air intake systems allow intake air to bypass the CBR filter elements when the blast protection system is not in the blast mode of operation. While this prevents the performance of the CBR filters from being impaired by a buildup of dirt, the reactive filter media deteriorates from exposure to air and requires replacement on a regular basis even if the filter bank has not been in service.

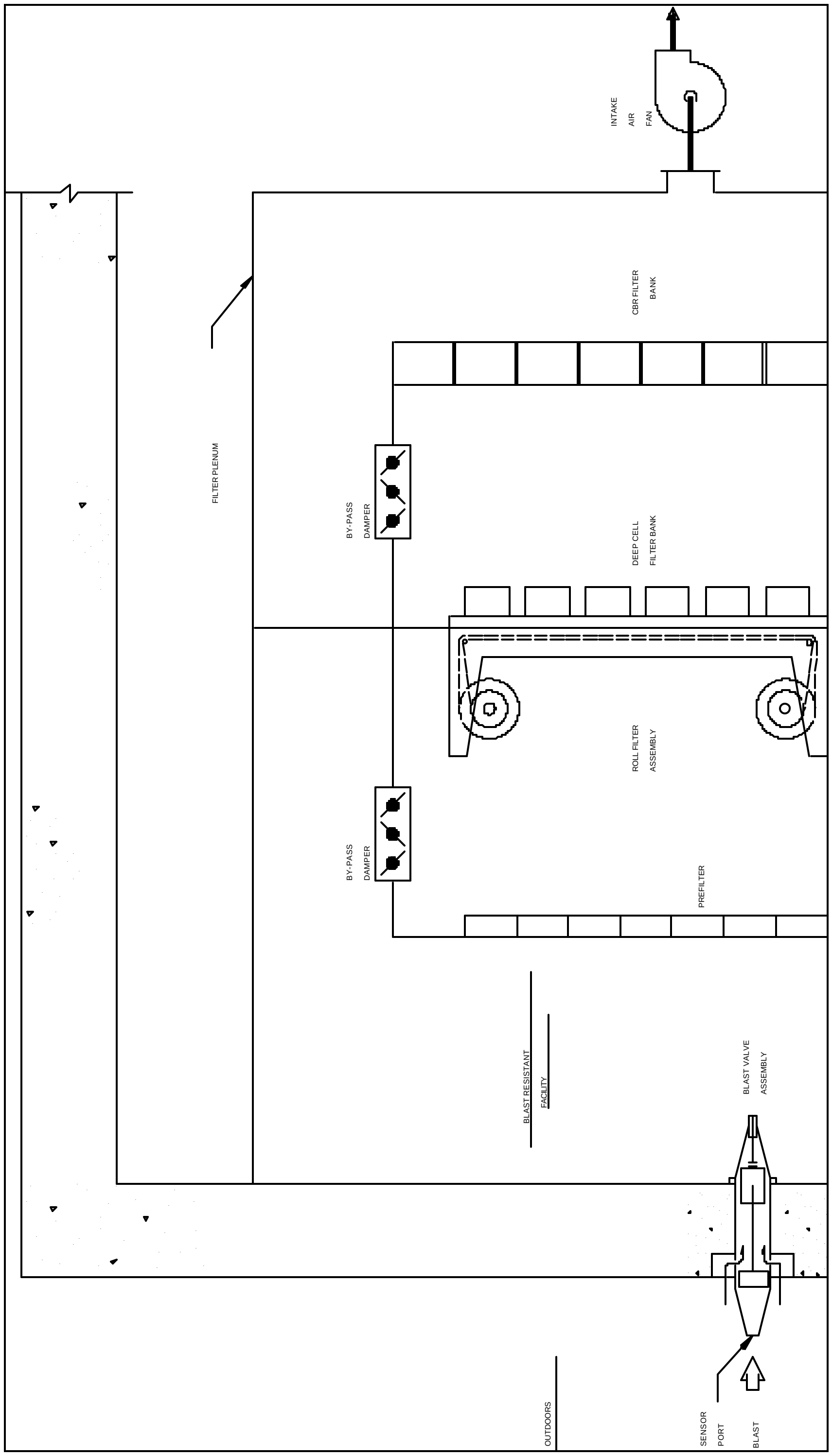

Figure 7-1. Blast-protected air intake system

(2) Figures 7-2 and 7-3 show blast-protected engine exhaust systems. On figure 7-2, the engine exhaust gas is discharged into a mixing chamber and the mixing chamber discharges to the outdoors through an array of blast valve assemblies (only one valve is shown on each figure). There are two features in this blast-protected engine exhaust system not usually found on engine exhaust systems in ordinary facilities, an exhaust cooling system and an exhaust isolation system.

(a) During normal operation, the engine exhaust is cooled to prevent damage to the blast valve assembly. During periods when the blast-protected facility is not in the blast mode of operation, other systems (such as cooling towers) can provide exhaust cooling by mixing with the engine exhaust. When the facility is in the blast mode of operation and many normal operations are curtailed, a water spray system similar to the system shown on figure 7-2 may be used.

(b) Another blast-protected exhaust system option is shown on figure 7-3. In this example, each engine exhaust duct has a high-temperature blast valve in the exhaust duct. When blast sensors trip the valve, an exhaust system relief valve (poppet valve) diverts the exhaust to an unoccupied space within the blast-protected facility. The exhaust systems on units not in operation are potential points of contaminant (exhaust gases from operating units, chemical or biological agents, radioactive particles, etc.) entry into protected spaces. Therefore, exhaust systems in blast-protected facilities may include valves (or dampers) in the exhaust duct system that automatically close when a unit is not in operation and the facility is in the blast mode of operation. The example blast-protected exhaust system shown on figure 7-2 has two isolation valves in series with an air purge in between to prevent backflow through the exhaust system of an out-of-service unit.

7-2. Engine intake and exhaust system major components

Descriptions of major system components for engine air intake and exhaust systems will be limited to components directly related to the operation of the engine. These components include combustion air particulate removal filters, intake air silencers, exhaust silencers, and air intake and exhaust duct materials of construction and duct system components. Items which impact the operation of the air intake and exhaust systems that are part of other systems (such as blast protection, compressed air, and industrial water) are described in other chapters of this manual.

a. Combustion air particulate removal filters. Common combustion air particulate removal filters are either wet type or dry type. Within the filter types, the filter elements may be either permanent (clean and reuse) or disposable.

(1) Three common wet type filters used to remove particulate matter from combustion air include the following.

(a) Viscous impingement filters are packed with fine strands of wire coated with oil. Air passing through the filter element impinges on the wires, and the oil coating traps the dust particles.

(b) Oil bath filters have a reservoir of oil. The filter housing is arranged to sweep the surface of the oil bath with the combustion air passing through the filter that agitates the bath. The oil coats and traps the particles, and the oil-coated particles collect in the oil reservoir.

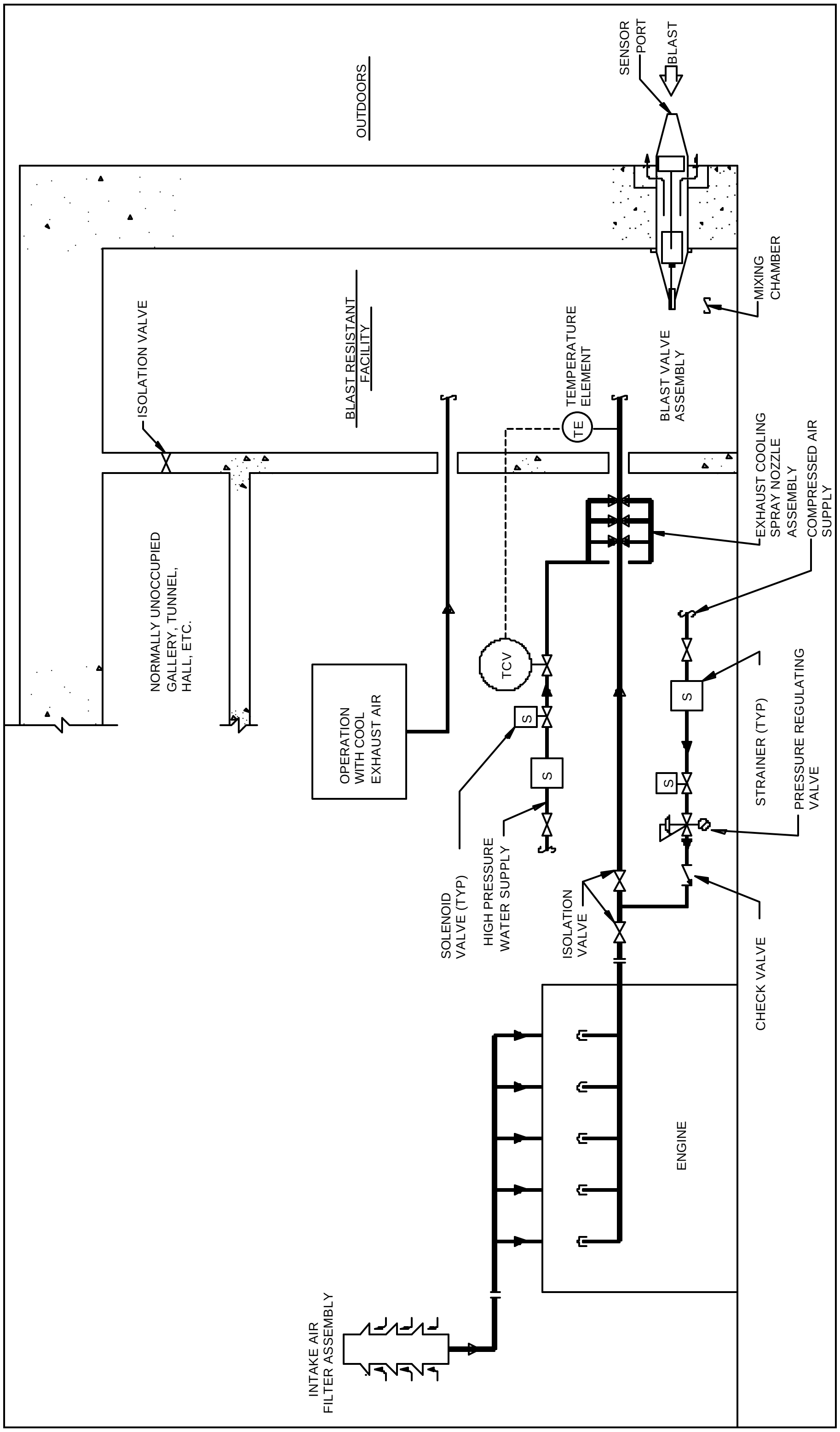

Figure 7-2. Blast-protected engine exhaust system

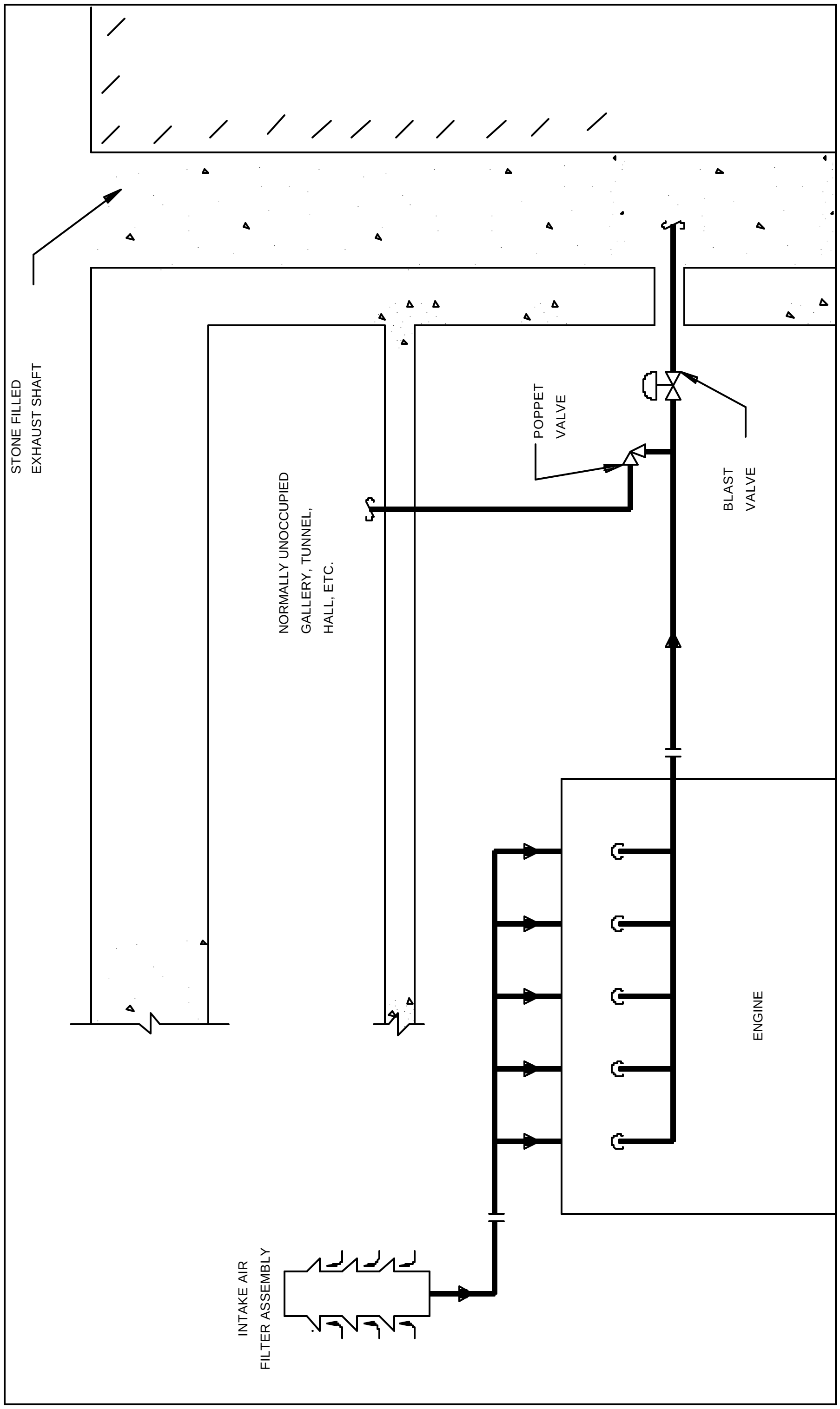

Figure 7-3. Blast-protected exhaust system

(c) Traveling screen filters are a combination of the viscous impingement and oil bath filters. A moving wire screen is continuously passed through an oil bath to be coated with oil. Air passing through impinges on the wire screen, and the oil coating traps the dust particles. As the wire screen passes through the oil bath, the dust particles are washed off the screen and collect in the oil reservoir. Most wet type filter elements are considered to be permanent elements.

(2) Many materials can be used to make filter media for dry type combustion air filters. Typical materials are fiberglass, polyester, cotton (a form of cellulose), and paper (also a form of cellulose). Common combustion air filter media types using these materials are woven, felted, pad, and mesh (or blanket). Most common combustion air dry type filter elements are replaceable elements. However, some units with a prefilter section designed to remove small volumes of relatively large diameter particles may use permanent filter elements.

b. Intake air and exhaust silencers. Common silencer units reduce (attenuate) the noise transmitted through the system by decreasing the velocity of the gas stream and absorbing the sound or by canceling sound waves with other sound waves from the same source. Most engine silencer units (intake and exhaust) are installed in-line with the duct system. Silencer units are usually several times larger in diameter than the duct. Silencer units may be a perforated flow-through tube which allows noise to escape into side chambers where the noise is absorbed. Silencer units may also be a baffled unit where changes in direction first separate and then recombine the gas stream causing sound waves to cancel each other. Common silencer units used with internal combustion engines have an internal volume equal to six to eight times the displacement of the engine. Noise transmitted through most combustion air intake systems has much less energy than noise transmitted through the exhaust gas system. The reduced noise energy in the intake system can be abated by the intake air filter media acting as a baffle and a noise absorbing mass. Therefore, most combustion air intake systems do not have a separate silencer unit. Some engines with turbocharger units that are driven by a turbine section turned by the exhaust gases may not require an exhaust silencer.

c. Intake and exhaust duct and duct components. Many materials may be used to fabricate the duct system and duct system components. One common material is carbon steel and another is stainless steel. The material selection is usually an economic decision during the initial design that considers the cost of the initial installation and future maintenance costs. Without careful study, repairs to existing systems should use the same materials and material thickness used in the original installation.

(1) The most common method for moving gases under moderate pressures is by means of some type of fan. There are two broad categories of fans: axial flow and centrifugal. Axial fans use propellers to move the air and are generally classed into three subtypes: propeller, tube axial, and vane axial. Centrifugal fans use fan wheels to move the air and are also classed into three subtypes according to the basic characteristics of the wheel used: forward curved, backward curved, and radial.

(2) A common expansion joint used to isolate rotating equipment from connected loads and to control thermal movements is a bellows type joint. These joints can accommodate axial, lateral, and angular motion, or limited combinations of each motion. For a specific set of operating conditions and a specific material of construction, the wall thickness of the expansion joint section, the outside diameter of the bellows, and the number of convolutions determine the amount of movement the expansion joint can accommodate.

(a) Bellows type joints can be fabricated from a wide variety of materials. Metal expansion joints are typically used in diesel engine air intake and exhaust gas systems. A common material of construction for these expansion joints is stainless steel. Expansion joints should be sized and

constructed in accordance with the Standards of the Expansion Joint Manufacturers Association, the appropriate sections of the American National Standards Institute (ANSI) Power Piping Codes, and the appropriate sections of the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Codes.

(b) Expansion joint failures are common maintenance problems. Common failure modes and the cause of the failures are shown in table 7-1. When faced with an expansion joint failure, maintenance personnel may make repairs to keep critical systems in operation. However, most field repairs change the response characteristics of the system that may cause problems in other parts of the system (e.g., engine manifold cracking, duct hanger deformation or failures, facility structural member deformation or failures, etc.). Repairs to expansion joints should be considered temporary, and arrangements should be made to replace the expansion joint as soon as possible. Except for the failure associated with chlorides leaching from insulating materials, all of the listed failure modes are the result of the expansion joint design not conforming to existing conditions. When the expansion joint is replaced, the design of the new expansion joint should reflect the current operating conditions. However, if there is a significant change in response characteristics of the replacement expansion joint relative to the original expansion joint, other modifications in the duct system may be required. This makes evaluating expansion joint problems and maintaining expansion joints a maintenance and facility engineering responsibility. If expansion joints fail because the actual movements to be accommodated by the joints exceed the capacity of the joints, the system needs to be reanalyzed and appropriate modifications need to be designed.

Table 7-1. Typical bellows material failures

Failure Mode	***Most Frequent Cause(s)***
Stress Corrosion	Chlorides, caustic, high temperature sulfurous gas acting on nickel alloys, leaching of chlorides from insulation.
Fatigue	Unanticipated vibration, unanticipated temperature changes.
Carbide Precipitation	Use of unstabilized materials at high temperatures.
Squirm and Burst	Over pressurization.

(3) Butterfly or slide gate type valves (or dampers) are commonly used to provide isolation in blast-protected exhaust gas systems. Butterfly valves should have an offset operating shaft design so that the disk contacts a continuous disk-sealing surface. While a variety of materials may be used in the valve body, valve trim components are typically stainless steel or materials with similar heat- and corrosion-resisting properties.